Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project: Outgoing Longwave Radiation

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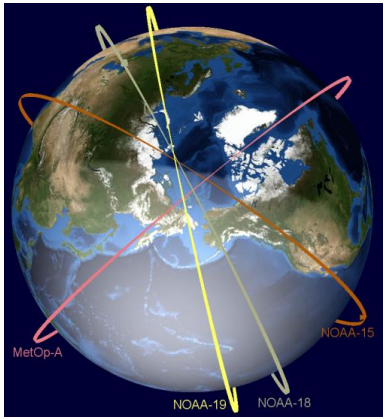
Introduction

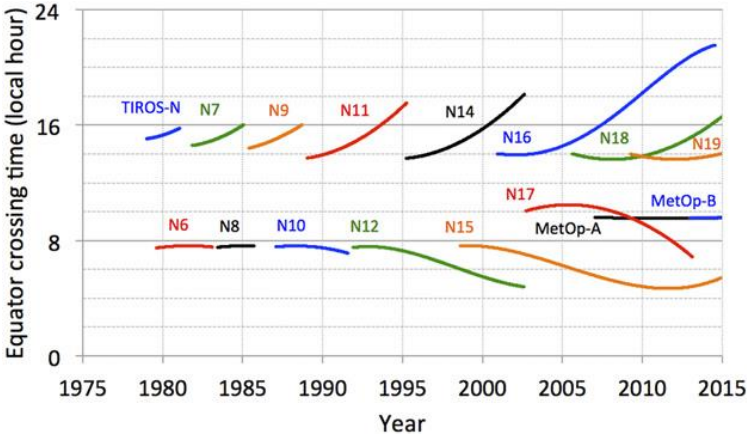
- **See previous presentation of Tom Akkermans**

- **Already many OLR products from AVHRR and HIRS covering the same time period (1979 onward).**

- **Interests of this new OLR product :**
  - New development using state of the art OLR (e.g. from CERES)
  - Targeting 0.25° spatial resolution
  - Synergy and consistency with the other CM SAF CLARA products (cloud products, surface radiation, RSF, ...)
  - Intercomparison with other OLR products (AVHRR, HIRS, CERES, GERB, ScaRaB …) and reanalysis
  - Triple collocation CERES – GERB – AVHRR
  - Possibility to merge with HIRS OLR products

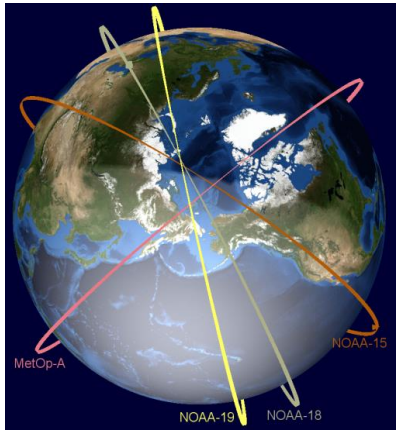
- **Some specific questions :**
  - Can we work with only channel 4 (AVHRR/1 instrument without channel 5)?
  - What is the effect of the number of satellites ?
  - What is the effect of orbital drift ?

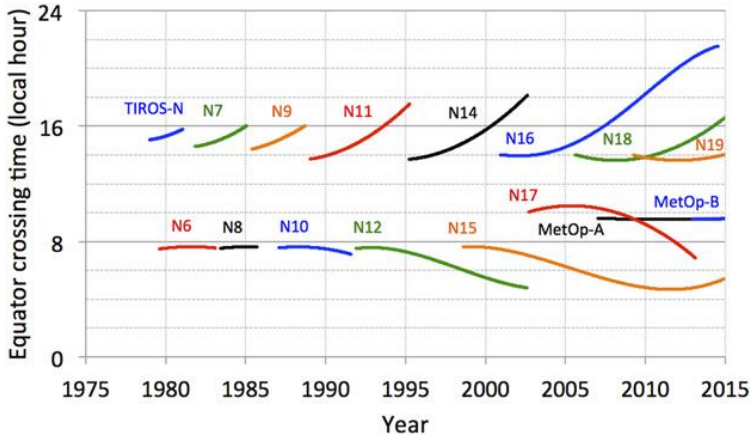




Content of the talk

- **Instantaneous OLR estimation**
  - Method
  - Results
- **Daily and Monthly mean**
  - Method
  - Results
  - Evaluation with CERES
- **Feedback loop results**
- **Summary and next steps**





Instantaneous OLR : method

Method:

- Regressions between AVHRR brightness temperatures T_4 (10.8µm) and T_5 (12µm) and CERES OLR:

$$OLR = c_0 + c_1 \cdot T_4 + c_2 \cdot (T_5 - T_4) + c_3 \cdot (T_4 - T_{surf}) + c_4 \cdot T_4^2 + c_5 \cdot T_4 \cdot (T_5 - T_4) + c_6 \cdot TCWV$$

  OLR from CERES SSF Edition 4a

  T_4 and T_5 aggregated in the CERES PSF (~20km).

- Ancillary interpolated from ERA5 reanalysis

  T_{surf} : surface skin temperature

  TCWV : Total Column Water Vapor

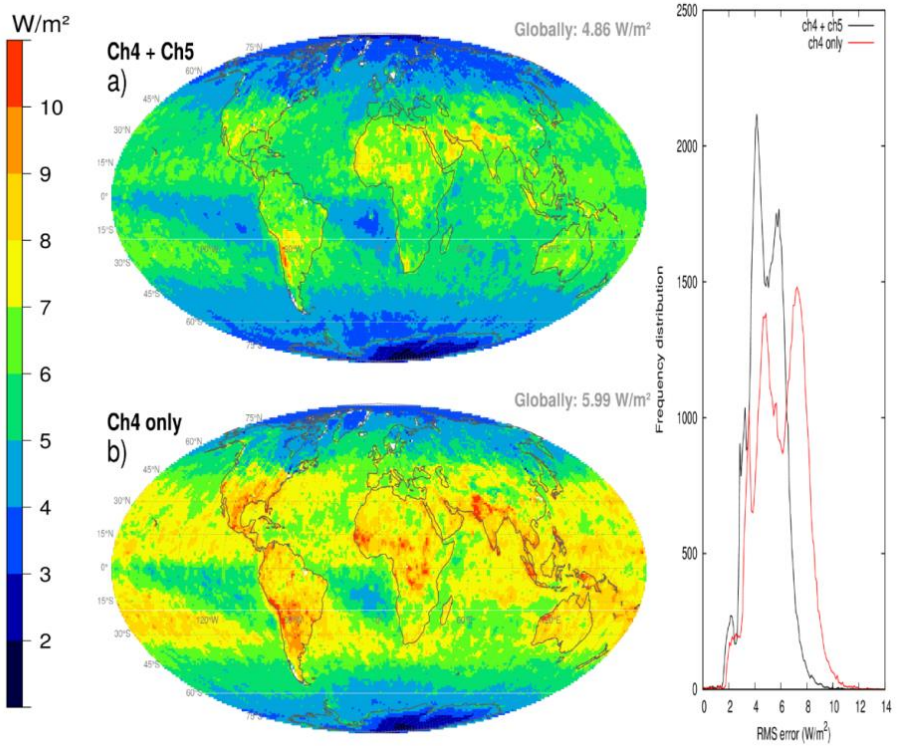
- Huge database of colocated coangular CERES-AVHRR observations (157 millions pairs)

- Regression coefficients $(c_0, c_1, \ldots, c_6)$ from least square fit after sorting the data in :
  - monthly bins (Jan, Feb, …, Dec)
  - 10° x 10° latitude – longitude boxes
  - 5° VZA bins

- AVHRR/1 instrument without channel 5 :

$$OLR = c_0 + c_1 \cdot T_4 + c_2 \cdot (T_4 - T_{surf}) + c_3 \cdot T_4^2 + c_4 \cdot TCWV$$

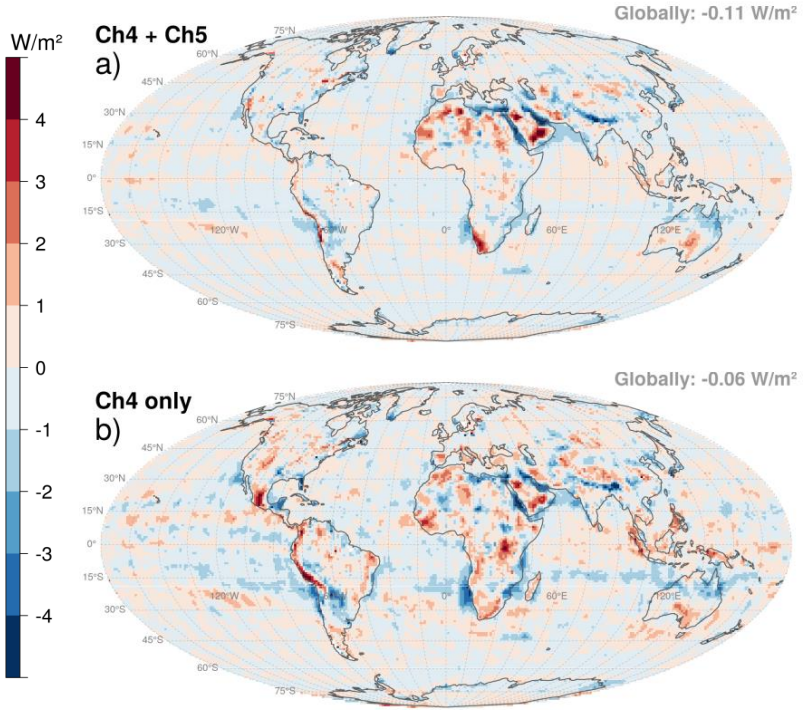
Results : RMS error of the regression in CERES PSF

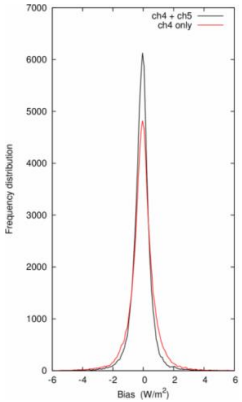


RMS error (Wm^{-2}) in CERES PSF (including collocation error) : (top) for the two channels regression and (bottom) when Channel 5 is not available

Instantaneous OLR : evaluation

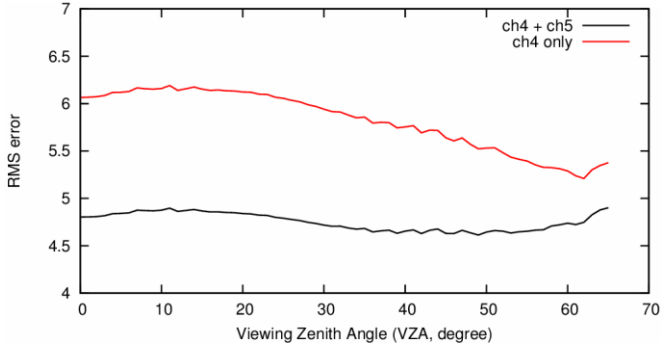
Results : regional bias





Systematic error (bias, Wm^{-2}) of OLR regression : (top) for the two channels regression (bottom) when Channel 5 is not available.

Results : VZA dependency of RMS

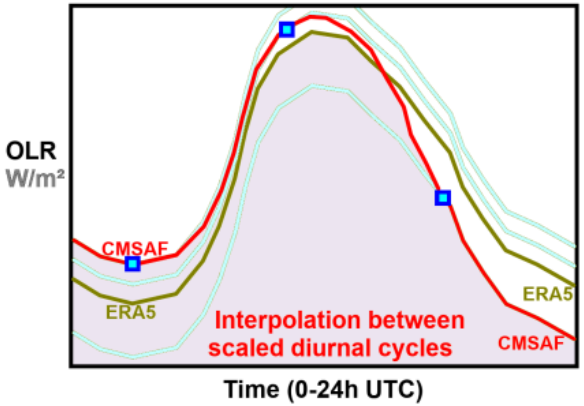


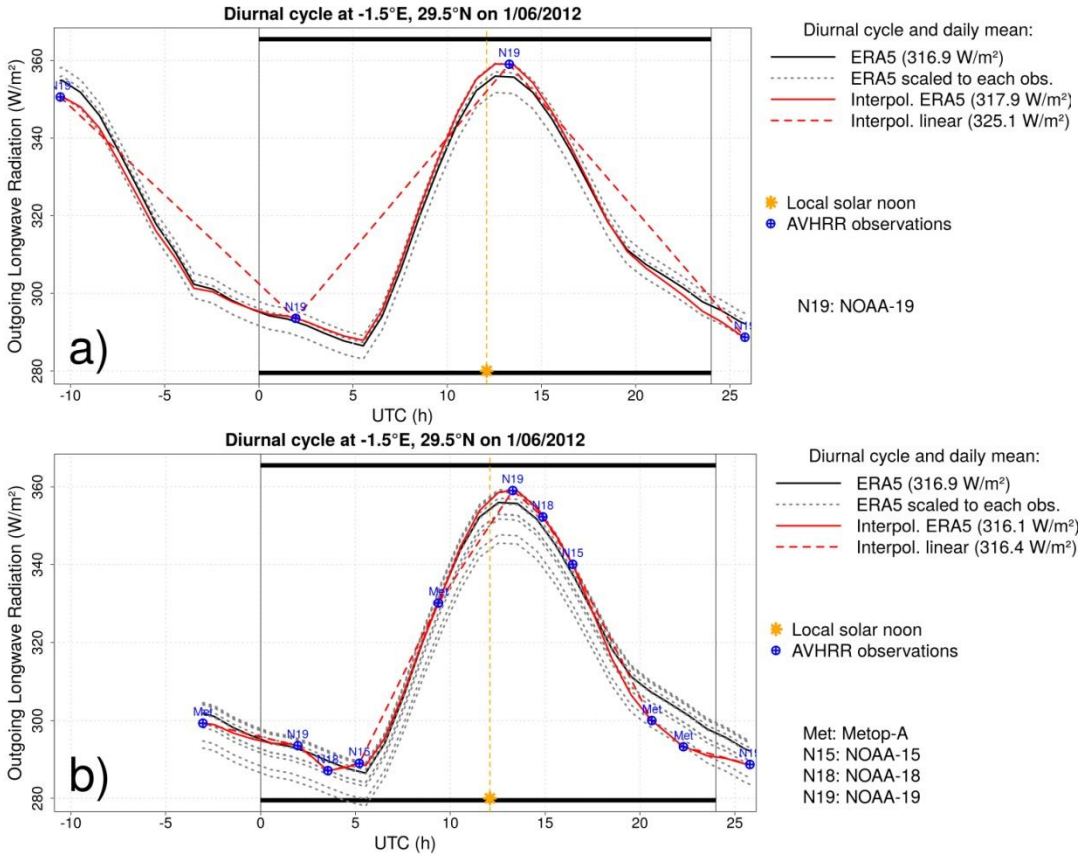
~50° : good angle for OLR estimation

Daily / monthly means : method

Method:

- Spatial aggregation of instantaneous OLR to 0.25°x0.25°
- Ocean and cloudy pixels: simple linear temporal interpolation between instantaneous OLR
- Clear land pixels: use of the shape of the ERA5 OLR diurnal variation rescaled to observations





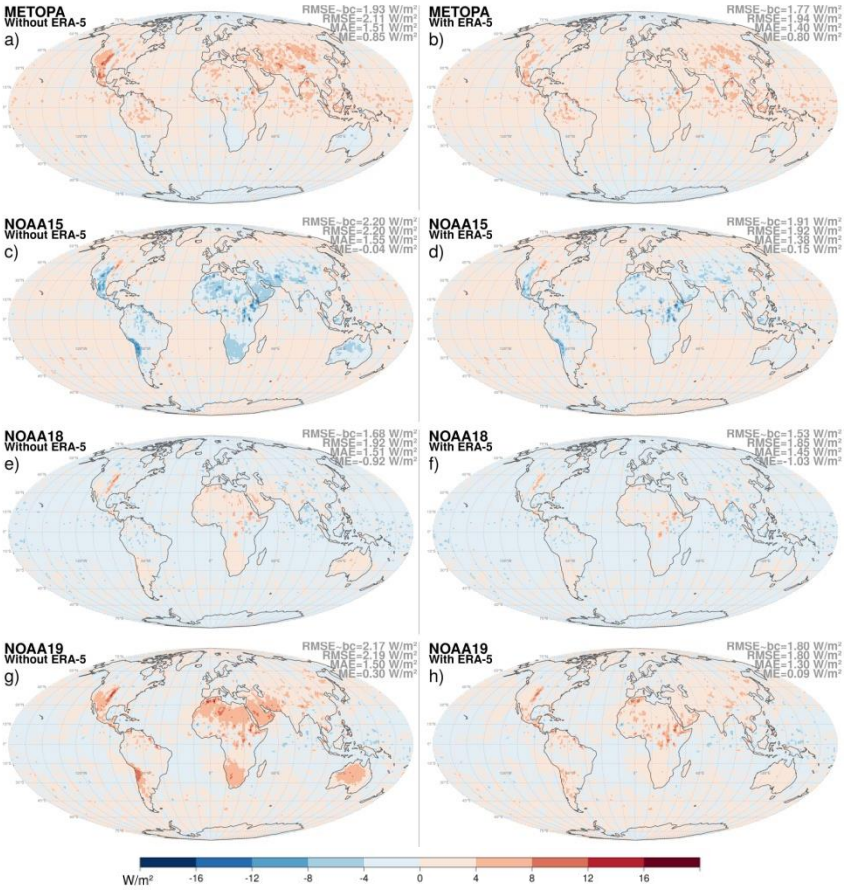
Daily/Monthly mean : evaluation

Metop-A
~09:30 LT
~21:30LT

NOAA-15
~05:00 LT
~17:00 LT

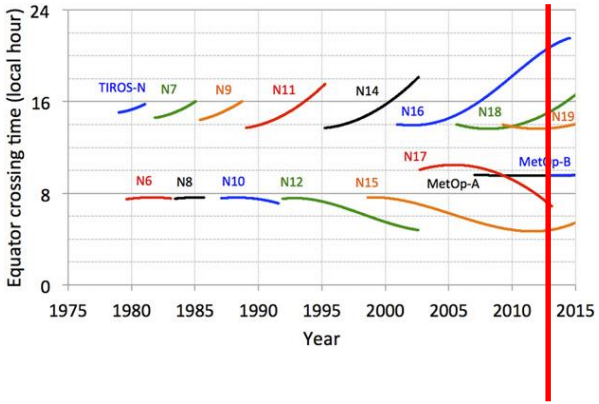
NOAA-18
~15:00 LT
~03:00 LT

NOAA-19
~13:45 LT
~01:45 LT



Difference between the June 2012 monthly mean OLR calculated by using the individual satellites and the reference monthly mean.

Reference monthly mean maps computed using 8 observations/day (from Metop-A, NOAA-15, NOAA-18, NOAA-19).



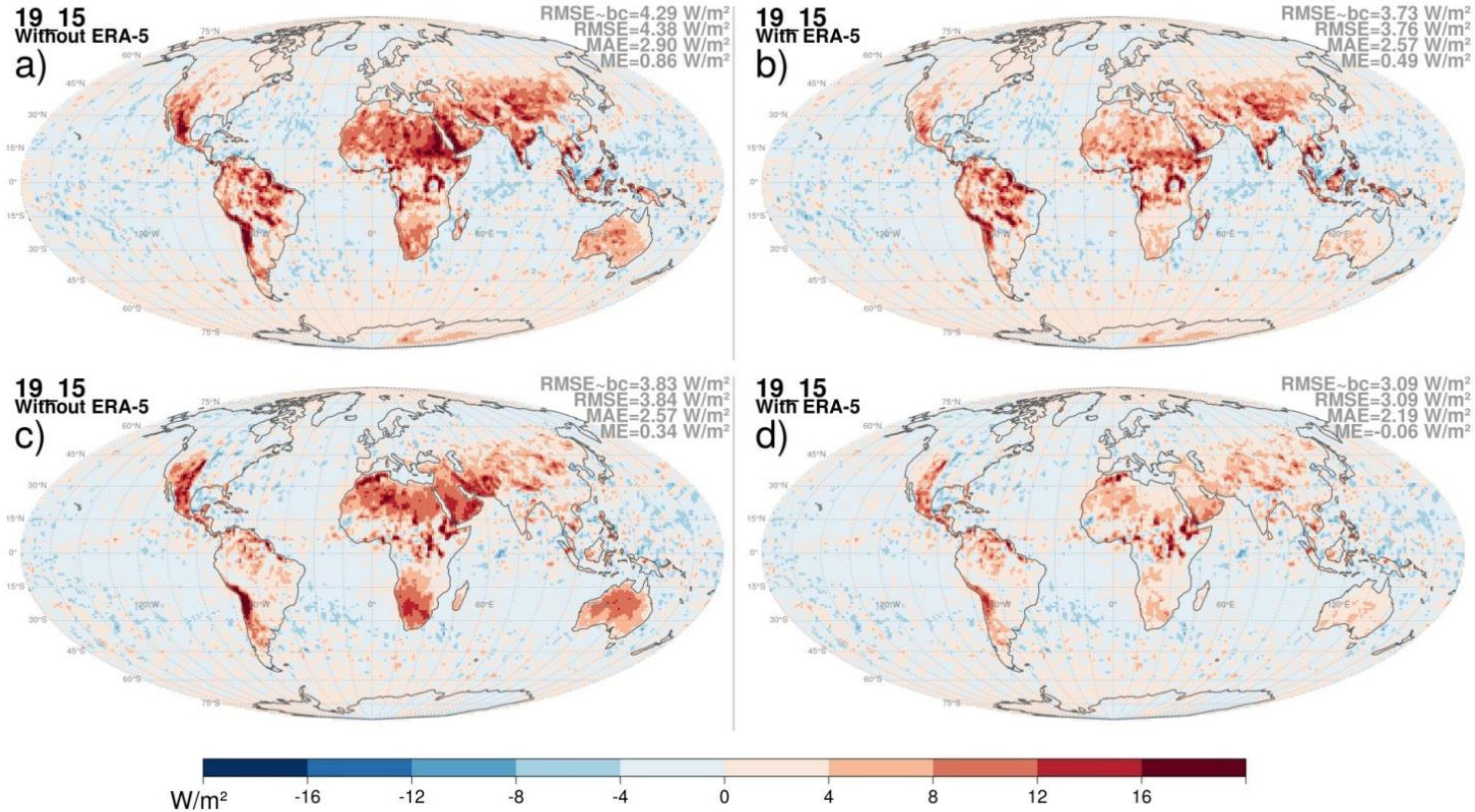
June 2012

Daily/Monthly mean : evaluation

Monthly mean OLR difference NOAA-19 – NOAA-15 (worst case)

April 2012

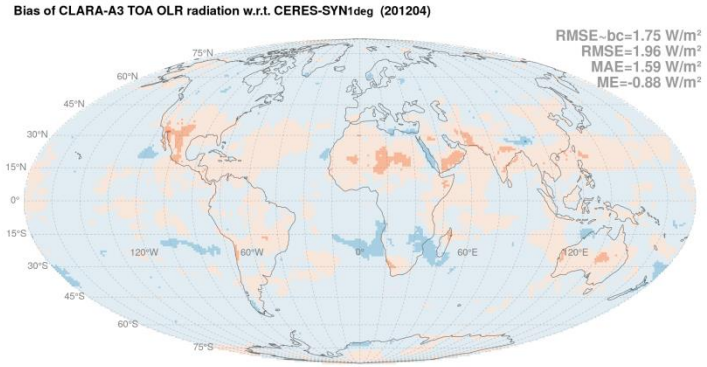
June 2012

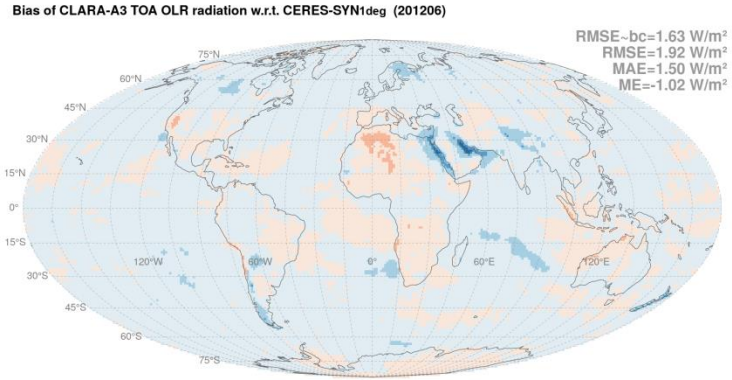


Difference between the monthly mean OLR calculated by only using NOAA-19 and by only using NOAA-15, for April (**a**,**b**) and June (**c**,**d**) 2012, with (**a**,**c**) linear temporal interpolation and (**b**,**d**) ERA5 diurnal cycle modeling for clear land pixels.

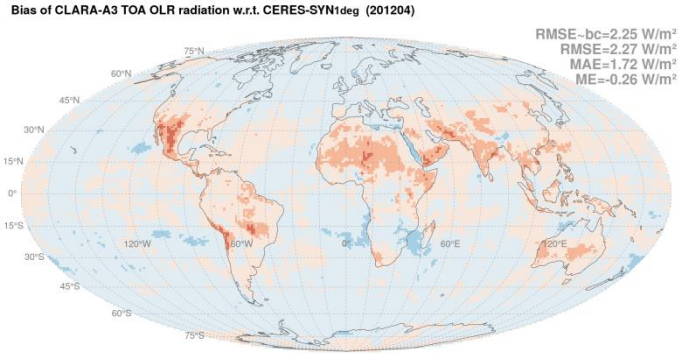
Overall comparison with CERES

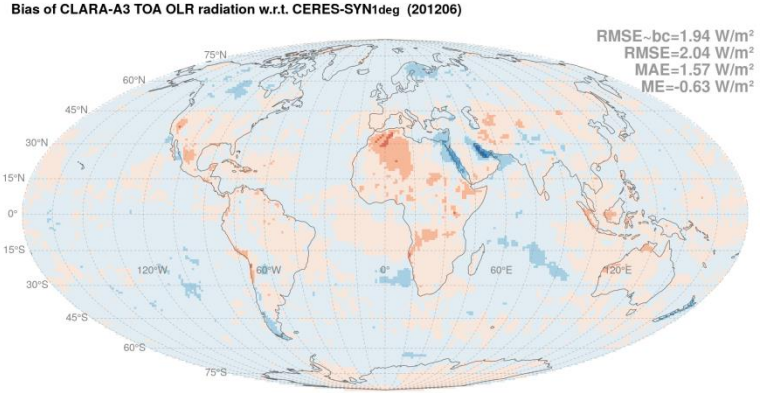
Monthly mean using 4 satellites (METOP-A, NOAA-15, NOAA-17, NOAA-19) - RMSE-bc of ~ 1.7 W/m²

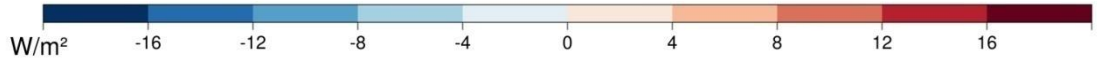




Monthly mean using 2 satellites (METOP-A + NOAA-19) - RMSE-bc of ~ 2.2 W/m²







Overall comparison with CERES

Monthly mean using <u>1 satellites</u>

RMSE-bc :

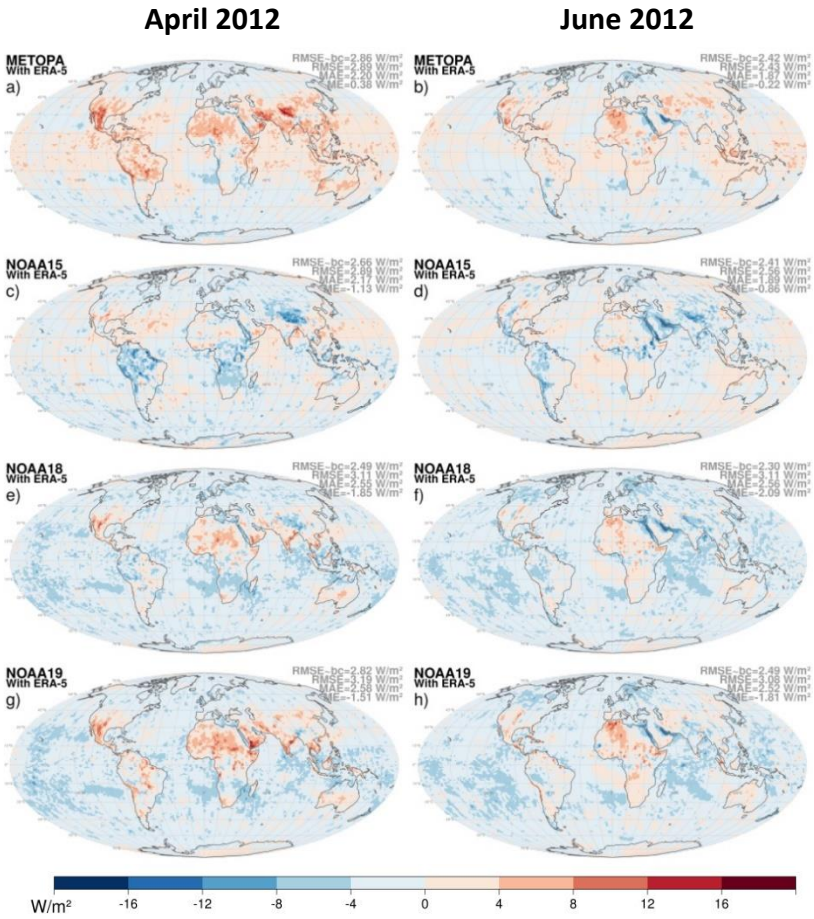
- **Metop-A : 2.6 W/m²**
- **NOAA-15 : 2.5 W/m²**
- **NOAA-18 : 2.4 W/m²**
- **NOAA-19 : 2.6 W/m²**

Metop-A
~09:30 LT
~21:30LT

NOAA-15
~05:00 LT
~17:00 LT

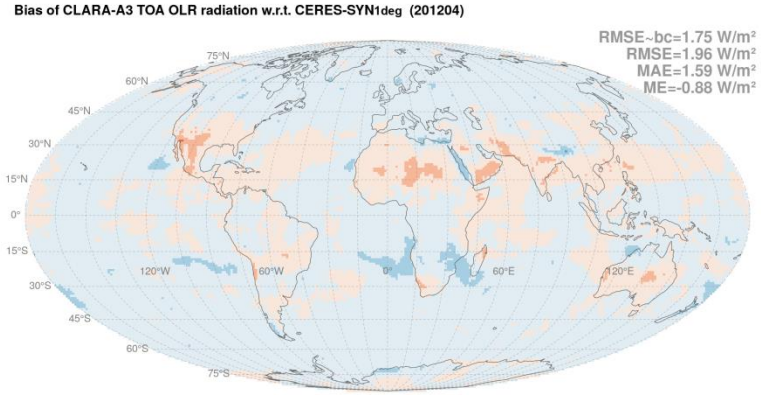
NOAA-18
~15:00 LT
~03:00 LT

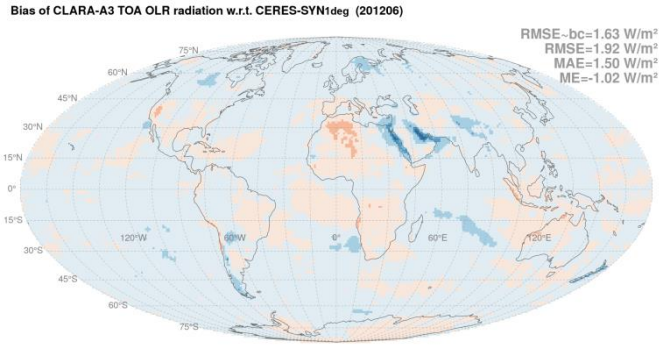
NOAA-19
~13:45 LT
~01:45 LT



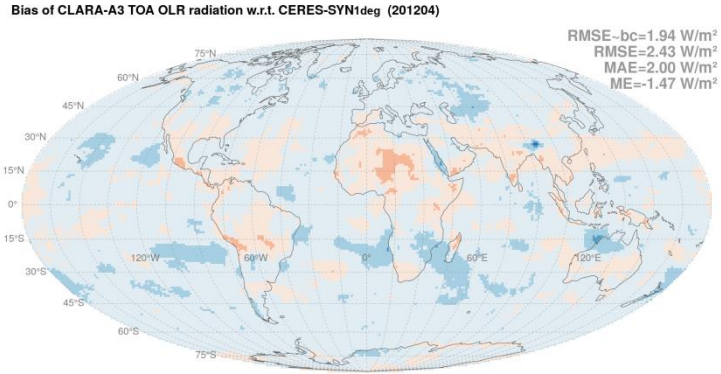
Overall comparison with CERES

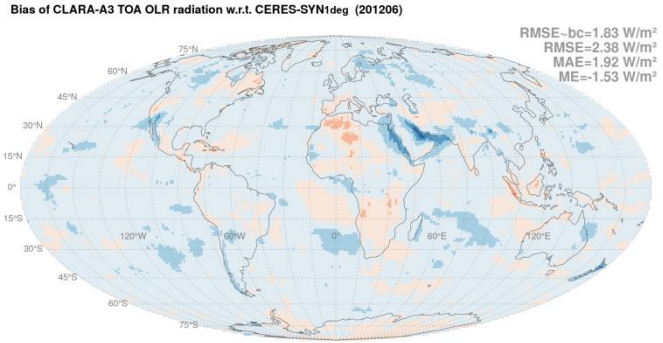
Regression for AVHRR/2 and AVHRR/3 (Ch4 + ch5)
RMSE-bc ~ 1.7 W/m²

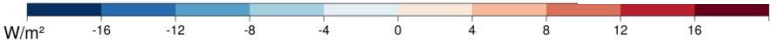




Regression for AVHRR/1 (Ch4 only)
RMSE-bc ~ 1.9 W/m²





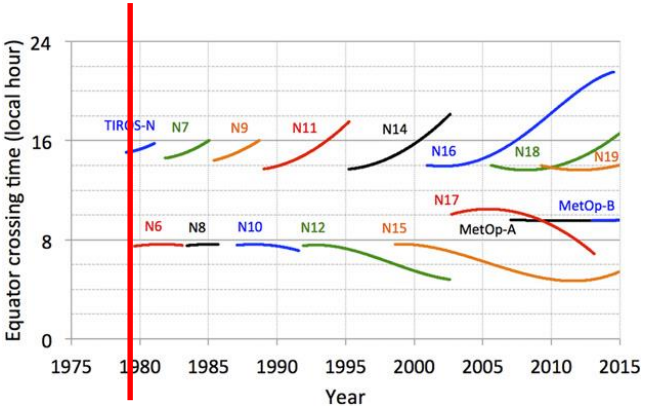


Evaluation on feedback loop

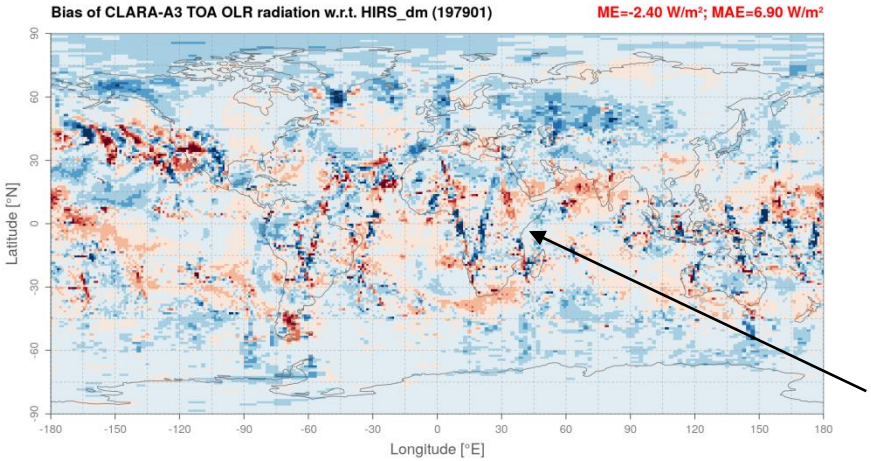
First month : January 1979

TIROS-N (AVHRR/1) only
~ 03:00 LT and 15:00 LT

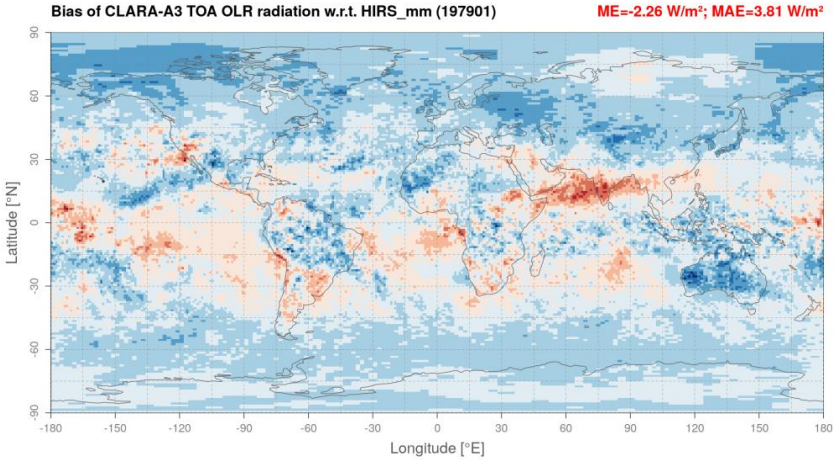
RMSE-bc wrt HIRS OLR
daily mean : ~ 7 W/m²
monthly mean : 4.01 W/m²



Jan 1979



End of swath visible in daily mean (to be investigated)

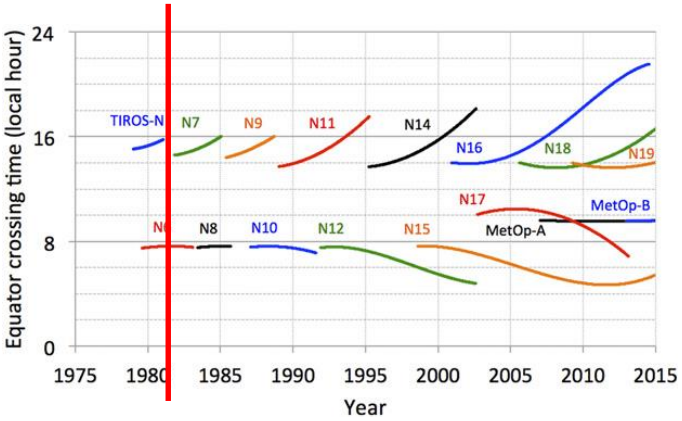


Evaluation on feedback loop

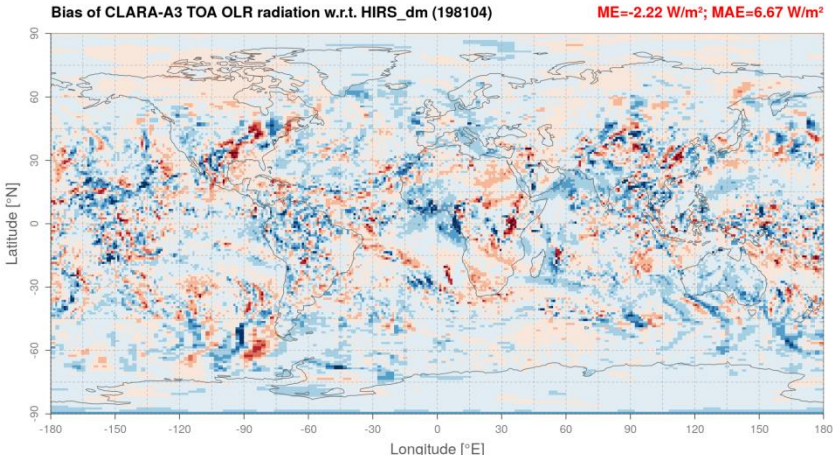
Second month : April 1981

NOAA-6 (AVHRR/1): ~07:30 LT and ~19:30 LT

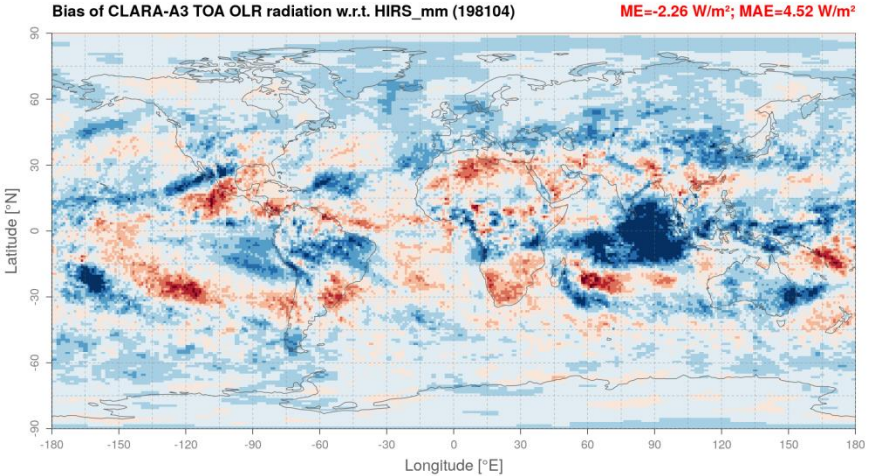
RMSE-bc wrt HIRS OLR
daily mean : ~ 7 W/m²
monthly mean : 5.66 W/m²



April 1981



Daily mean ok



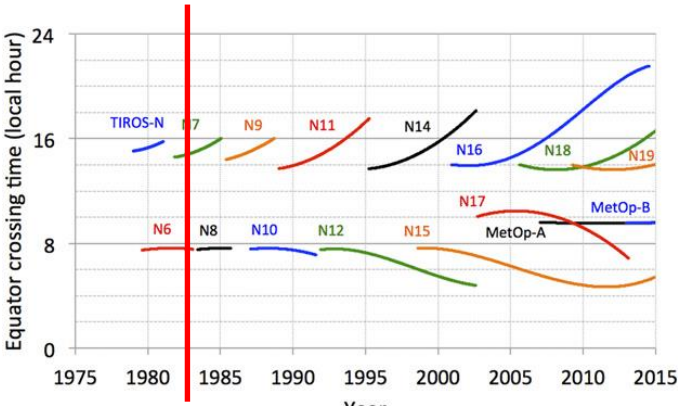
Monthly mean evaluation affected by HIRS data gap (AVHRR ok)

Evaluation on feedback loop

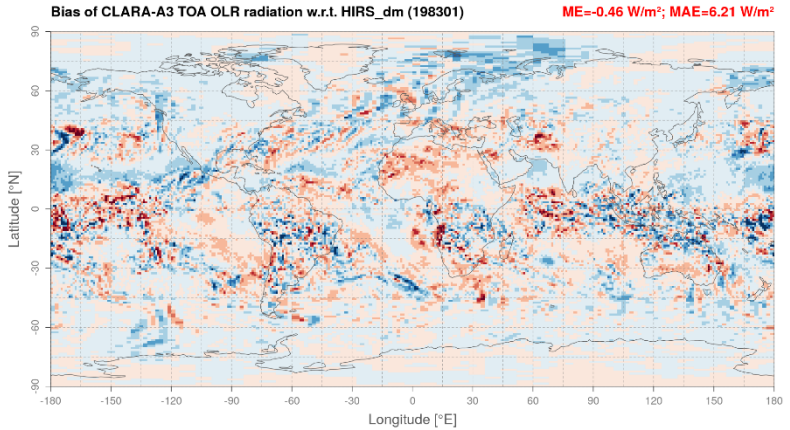
Third month : Jan 1983

NOAA-6 (AVHRR/1): ~07:30 LT
NOAA-7 (AVHRR/2): ~15:00 LT

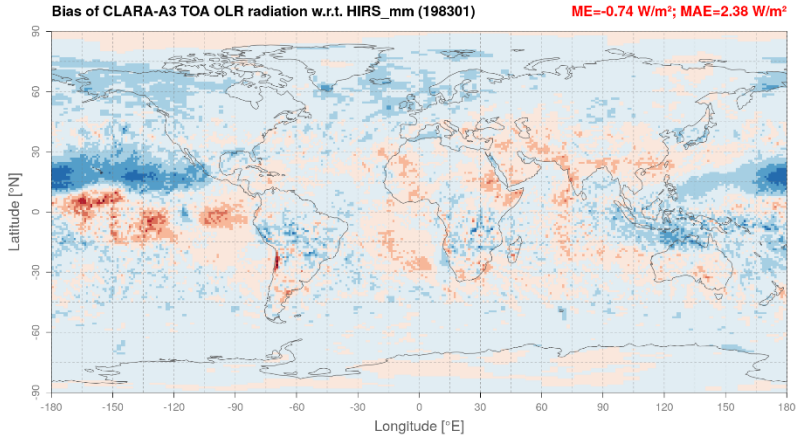
RMSE-bc wrt HIRS OLR
daily mean : ~ 7 W/m²
monthly mean : 3.19 W/m²



Jan 1983



Daily mean ok



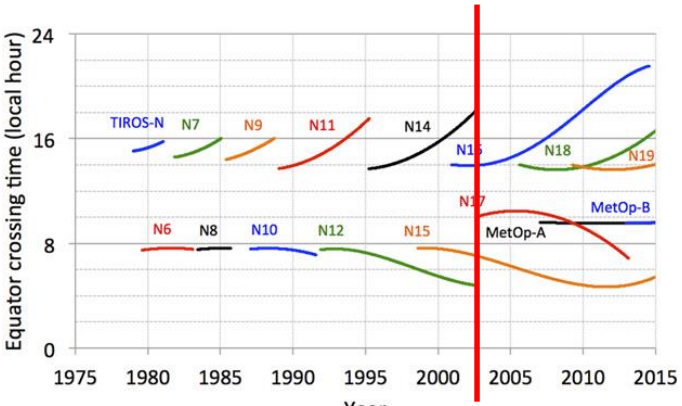
Monthly mean ok

Evaluation on feedback loop

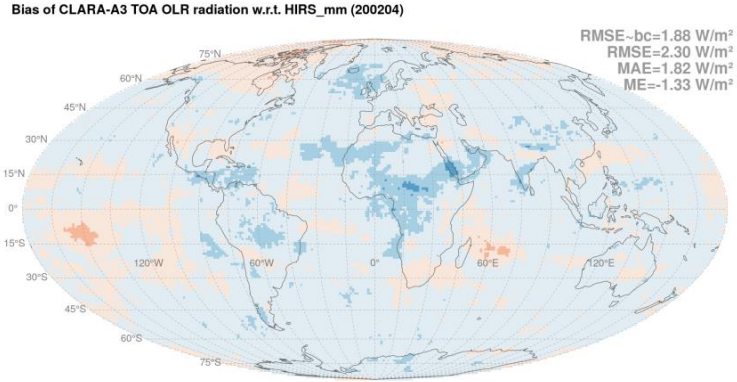
April 2002 – Monthly mean

NOAA-15 (AVHRR/3): ~07:00 LT
NOAA-16 (AVHRR/3): ~14:00 LT

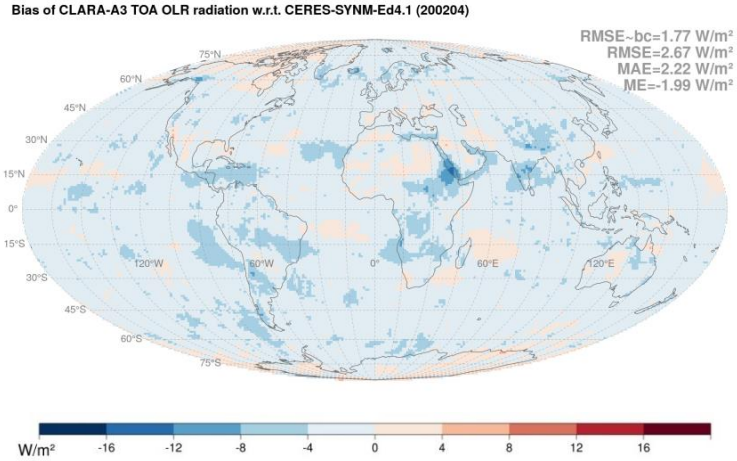
RMSE-bc
wrt HIRS OLR : 1.88 W/m²
wrt SYN : 1.77 W/m²



April 2002



HIRS



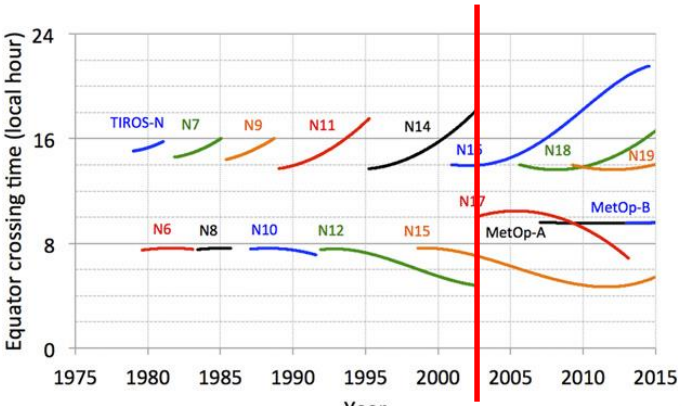
CERES SYN

Evaluation on feedback loop

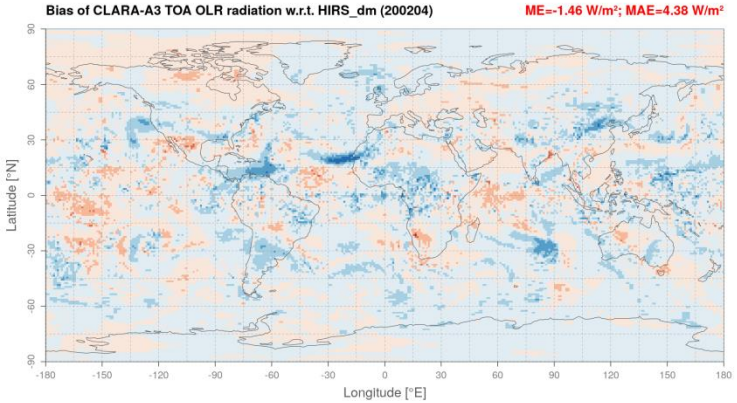
April 2002 – Daily mean

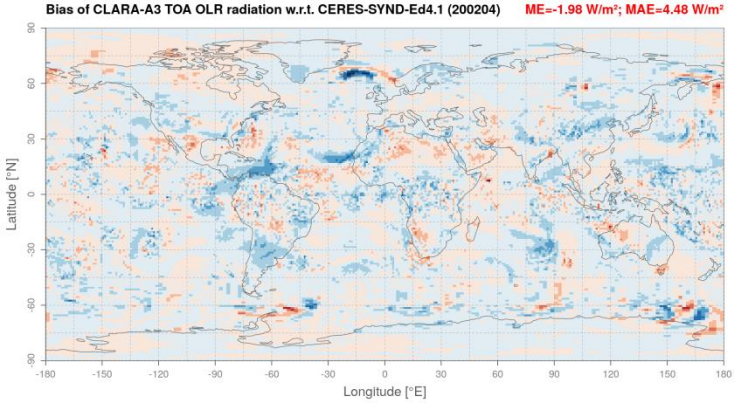
NOAA-15 (AVHRR/3): ~07:00 LT
NOAA-16 (AVHRR/3): ~14:00 LT

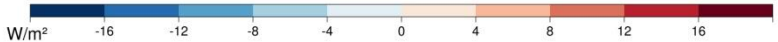
RMSE-bc
wrt HIRS OLR : 5.5 W/m²
wrt SYN : 5.6 W/m²



April 2002

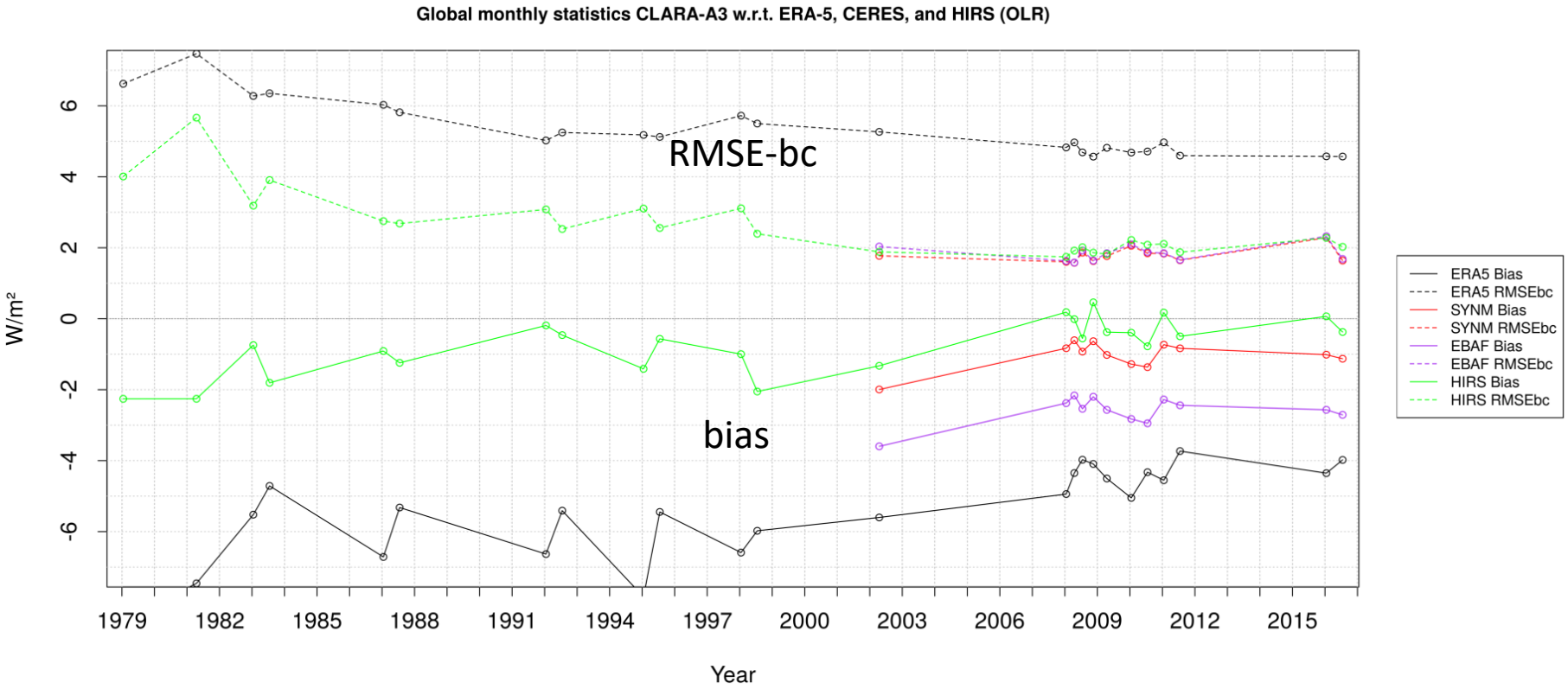






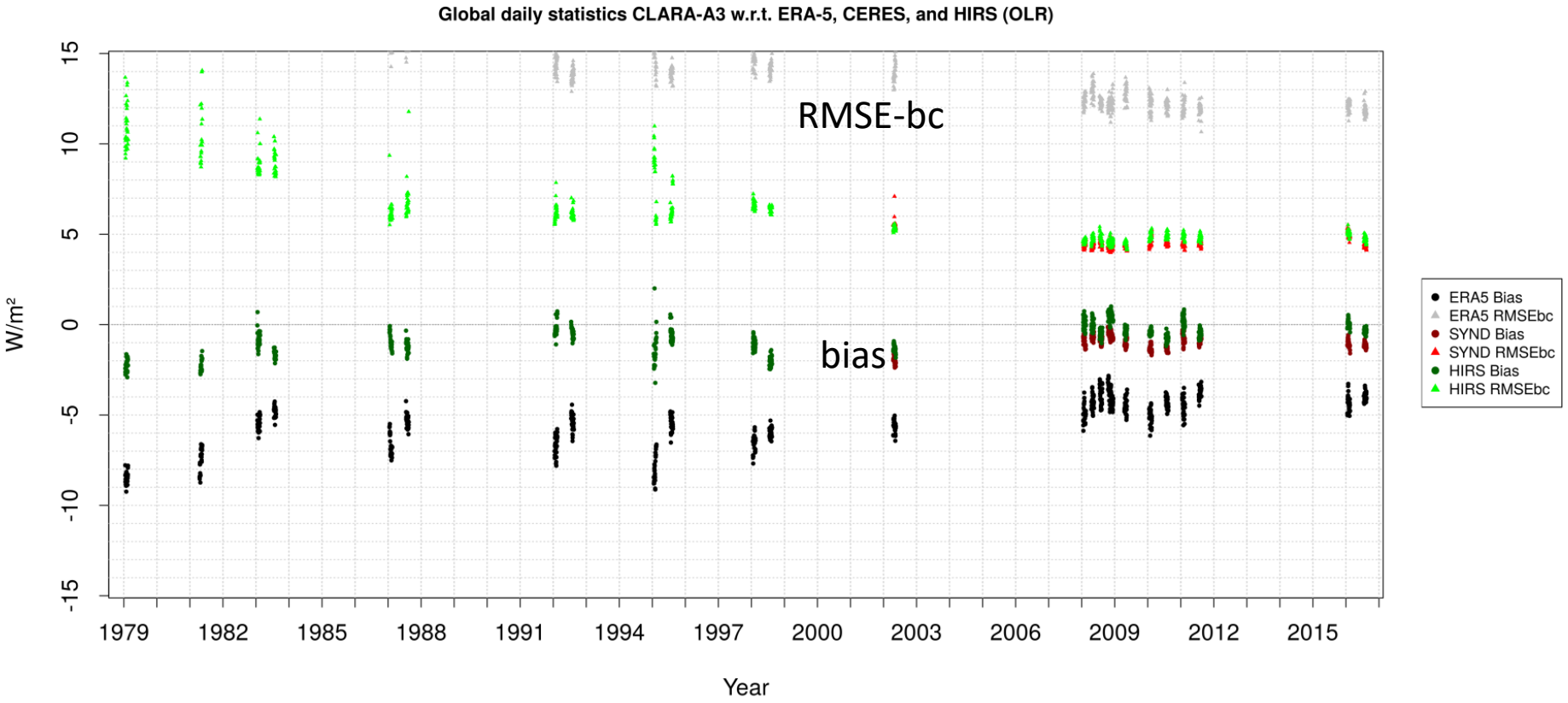
Evaluation on feedback loop

Monthly mean



Evaluation on feedback loop

Daily mean



Triple collocation

- Triple collocation of 1°x1° monthly means OLR from
  - CERES EBAF (Ed4.1)
  - CM SAF GERB/SEVIRI (ed2.0)
  - CM SAF CLARA (A3)

- Assumption : the uncertainties (retrieval errors) of the 3 products are not correlated.

- In average uncertaincy (at 1-sigma) of

  CERES EBAF : 0.87 ± 0.22 W/m²
  CLARA A3 : 1.73 ± 0.23 W/m²
  GERB ed02 : 1.32 ± 0.63 W/m²

- Using CERES EBAF as the "truth" (no error) uncertainties (at 1-sigma) :

  CLARA : 1.96 W/m²
  GERB : 1.62 W/m²

Month	1-sigma uncertainties (W/m²)		
	EBAF	CLARA	GERB
200501	1.275	1.519	3.035
200801	1.097	1.293	0.995
200804	0.557	1.744	1.987
200807	0.921	1.984	0.843
200810	0.745	1.636	1.359
200811	0.653	1.749	1.247
201001	0.557	1.940	1.241
201007	0.935	2.125	0.685
201101	1.043	1.874	1.082
201107	0.737	1.487	1.084
201206	1.090	1.692	0.958
Average	0.874	1.731	1.320
Std.Dev.	±0.229	±0.232	±0.631

Summary

- Regression between CERES OLR and AVHRR ch-4 and -5 BTs
- Instantaneous OLR RMS error ~ 5W/m² (~ 6W/m² for AVHRR/1)
- Diurnal cycle modelling using ERA5 (for clear land warming)
- Feedback loop gives encouraging results :

  RMS error ~ 4W/m² → 2W/m² for monthly mean

  RMS error ~ 10 W/m² → 4.5W/m² for daily mean

- Next steps: full CDR processing, comprehensive validation, CDR release expected Q4 2021, development and inclusion of AVHRR-*like* from VIIRS (S-NPP, NOAA-20).


remote sensing

MDPI

Article

The Climate Monitoring SAF Outgoing Longwave Radiation from AVHRR

Nicolas Clerbaux *, Tom Akkermans, Edward Baudrez, Almudena Velazquez Blazquez, William Moutier, Johan Moreels and Christine Aebi

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Abstract: Data from the Advanced Very High Resolution Radiometer (AVHRR) have been used to create several long-duration data records of geophysical variables describing the atmosphere and land and water surfaces. In the Climate Monitoring Satellite Application Facility (CM SAF) project, AVHRR data are used to derive the Cloud, Albedo, and Radiation (CLARA) climate data records of radiation components (i.e., surface albedo) and cloud properties (i.e., cloud cover). This work describes the methodology implemented for the additional estimation of the Outgoing Longwave Radiation (OLR), an important Earth radiation budget component, that is consistent with the other CLARA variables. A first step is the estimation of the instantaneous OLR from the AVHRR observations. This is done by regressions on a large database of collocated observations between AVHRR Channel 4 (10.8 μm) and 5 (12 μm) and the OLR from the Clouds and Earth's Radiant Energy System (CERES) instruments. We investigate the applicability of this method to the first generation of AVHRR instrument (AVHRR/1) for which no Channel 5 observation is available. A second step concerns the estimation of daily and monthly OLR from the instantaneous AVHRR overpasses. This step is especially important given the changes in the local time of the observations due to the orbital drift of the NOAA satellites. We investigate the use of OLR in the ERA5 reanalysis to estimate the diurnal variation. The developed approach proves to be valuable to model the diurnal change in OLR due to day/night time warming/cooling over clear land. Finally, the resulting monthly mean AVHRR OLR product is intercompared with the CERES monthly mean product. For a typical configuration with one morning and one afternoon AVHRR observation, the Root Mean Square (RMS) difference with CERES monthly mean OLR is about 2 Wm^{-2} at 1° × 1° resolution. We quantify the degradation of the OLR product when only one AVHRR instrument is available (as is the case for some periods in the 1980s) and also the improvement when more instruments are available (e.g., using METOP-A, NOAA-18, NOAA-18, and NOAA-19 in 2012). The degradation of the OLR product from AVHRR/1 instruments is also quantified, which is done by "masking" the Channel 5 observations.

Keywords: outgoing longwave radiation; OLR; TOA; broadband; flux; AVHRR; CERES

1. Introduction

The Climate Monitoring Satellite Application Facility (CM SAF) [1] has been established to provide an important contribution to the global climate monitoring. One of the main successes of this project is the generation of the Cloud, Albedo, and Radiation (CLARA) dataset based on the global observations from the Advanced Very High Resolution Radiometer (AVHRR) [2] onboard the NOAA and METOP satellites. A first edition of the CLARA dataset [3] was released in 2013, and a second one followed in 2017 [4]. CM SAF is currently developing a third edition, CLARA-A3, with a planned

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Thanks for your attention!

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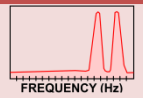
2. Outgoing Longwave Radiation

Part1 / Part2

Level-2 processing: instantaneous observations

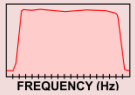
Outoing Longwave Radiation (OLR)

AVHRR ch4: 11µ | AVHRR ch5: 12µ



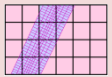
"all-in-one" conversion from narrowband directional brightness temp. to broadband hemispherical flux, based on database with coangular AVHRR-CERES obs.

OLR *[W/m²]*



Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

remapped OLR (0.25°)



Reflected Solar Flux (RSF)

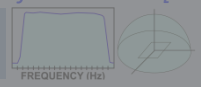
AVHRR ch1: 0.6µ | AVHRR ch2: 0.9µ

NB-to-BB regressions based on database with co-angular AVHRR-CERES obs.

Broadband reflectance

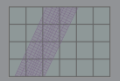
ADM's from CERES [Loeb et al.]

Albedo *[%]* *(hemispherical)*



Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

remapped Albedo (0.25°)



Part3

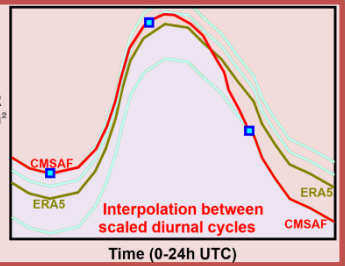
Level-3 processing: daily mean

OLR

ERA5 diurnal cycle OLR

ERA5 diurnal cycle scaled to Level-2 observations, then interpolate :

Daily mean

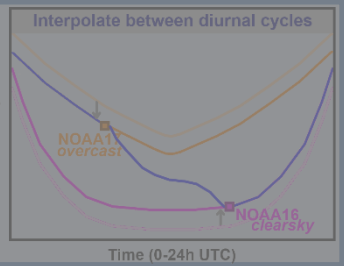


RSF

Method: Young et al. ('98): match scene-dependent average diurnal cycle to observations, then interpolate

Convert albedo to flux

Daily mean RSF [W/m²]



P4

Level-3b processing

OLR

Monthly mean

RSF

Monthly mean RSF